Symposium in honour of Robert Roosen

"A deeper look into matter"

19th of Oct 2012 - 14h-16h
Promotiezaal VUB - D2.01
Campus Oefenplein, Brussel

"Robert Roosen at the IIHE"
Prof. Catherine De Clercq

"Charm & Beauty experiments"
Prof. em. Stefaan Tavernier

"The H1 experiment at HERA"
Prof. Eckhard Elsen (DESY)

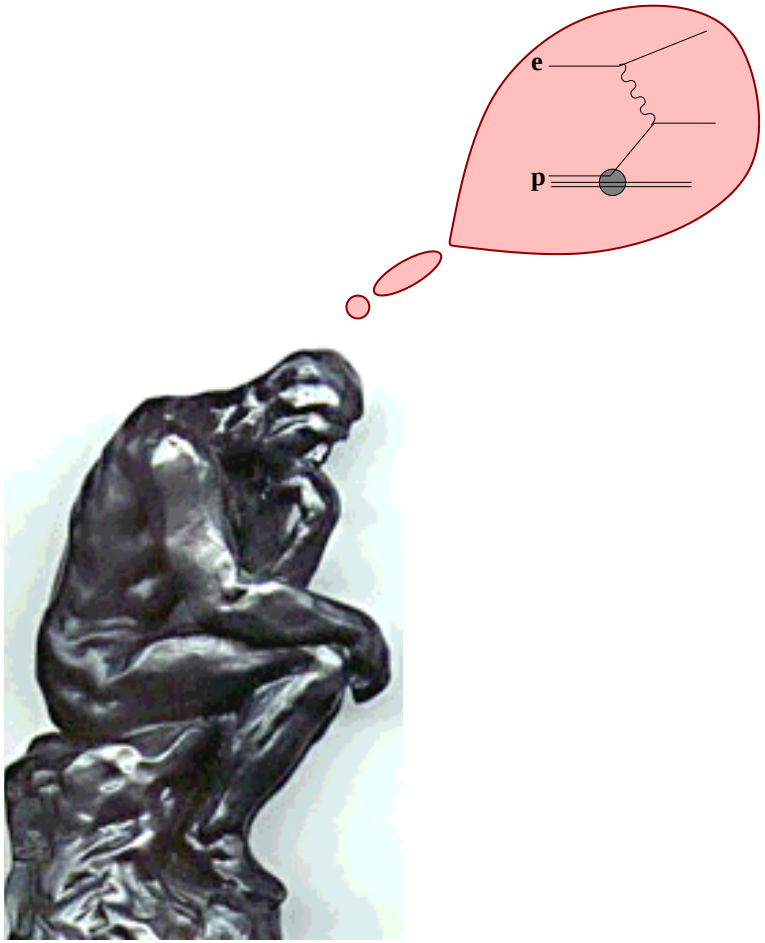
"The legacy of HERA"
Dr. Sergey Levonian (DESY)

Reception from 16h – at the IIHE

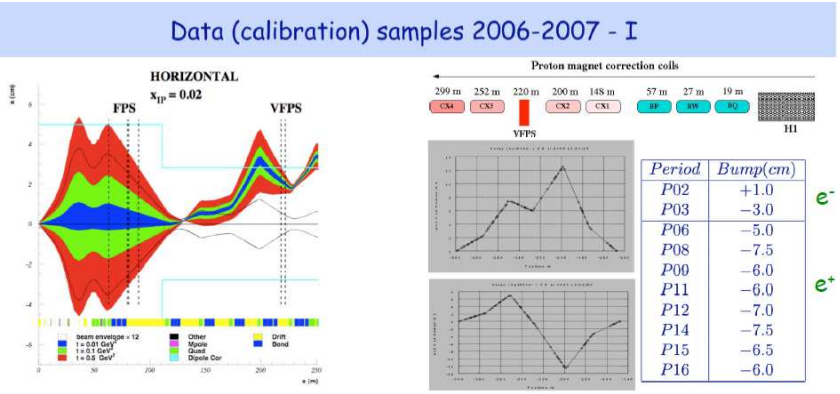
iihe BRUXELLES BRUSSEL

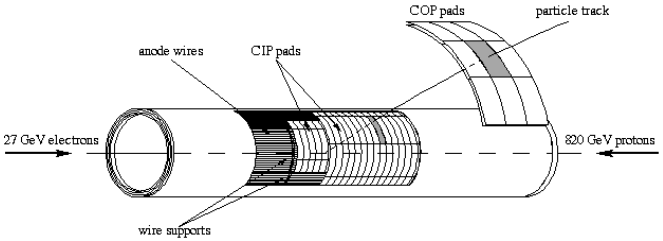
Vrije Universiteit Brussel

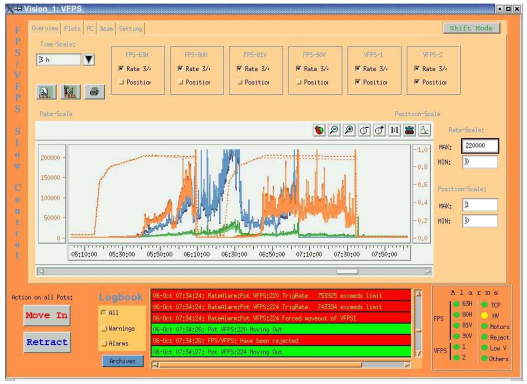
In the beginning the was the Idea...



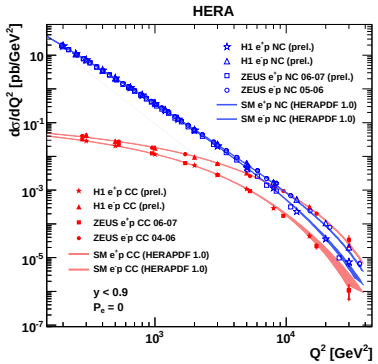
...then a lot of Hard Work...

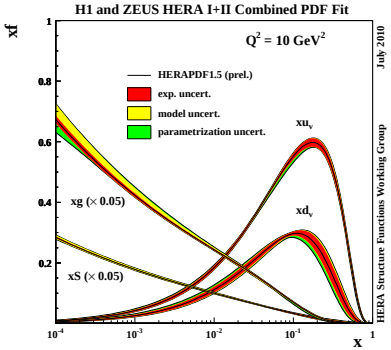


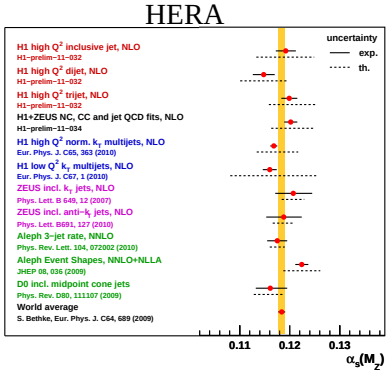


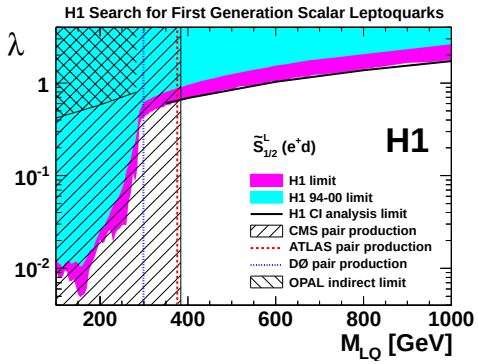


...and finally...



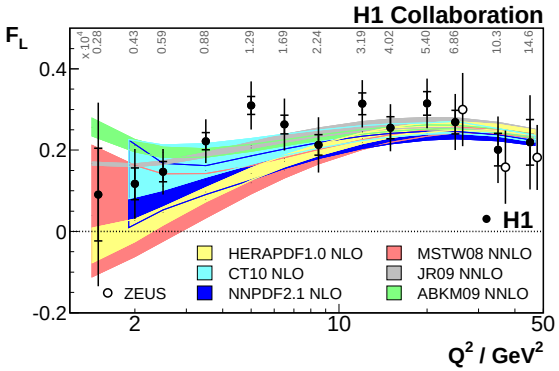


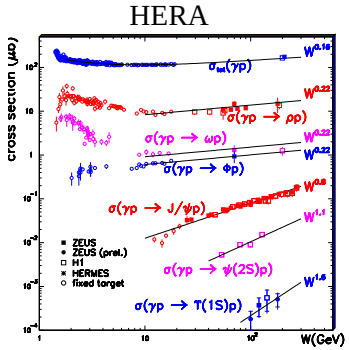


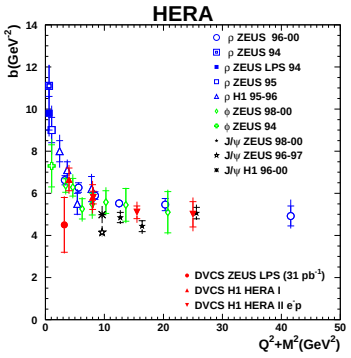


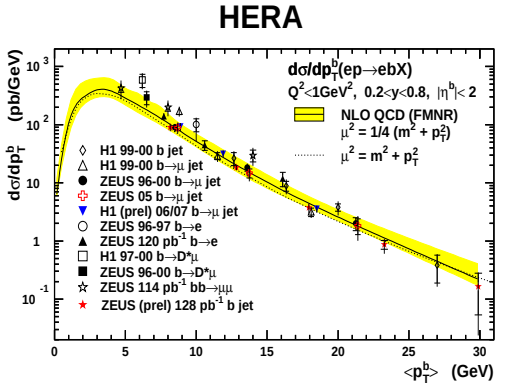
The Legacy of HERA

S. Levonian (DESY)

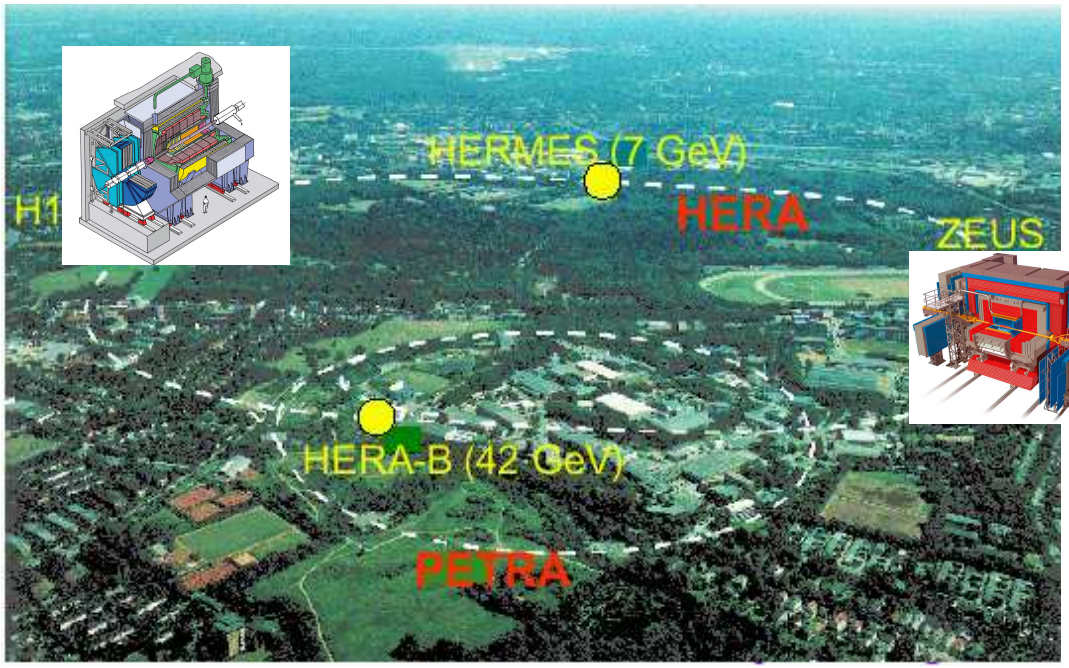


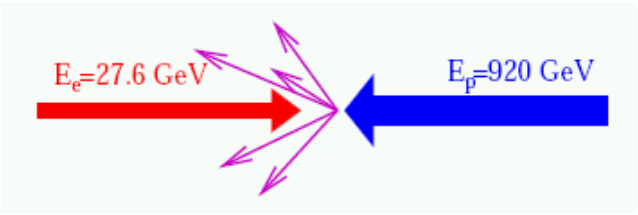






HERA: The World's Only ep Collider





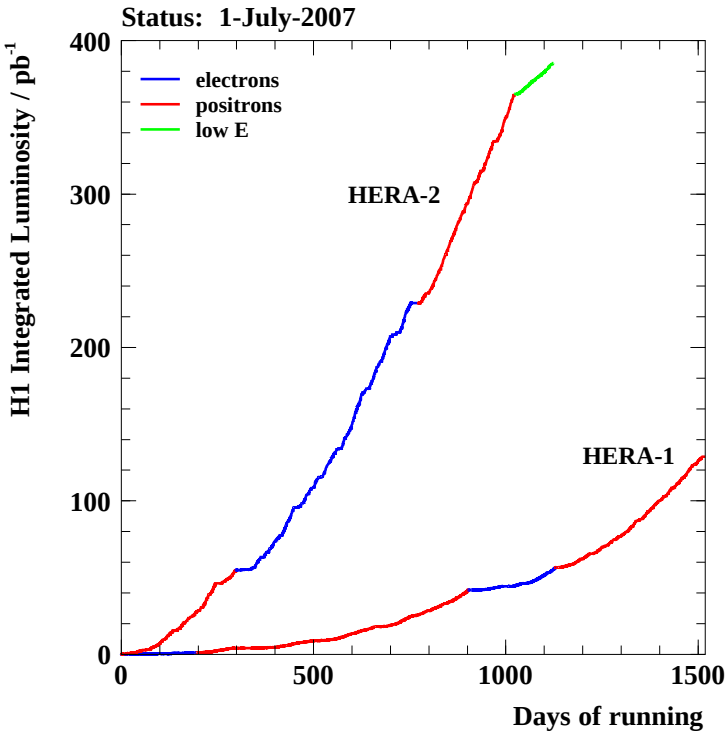
- 1998 E_p upgrade: $820 \Rightarrow 920$ GeV
  ($\sqrt{s}$: $301 \Rightarrow 319$ GeV)
- 2001 HERA-2 upgrade: $\mathcal{L} \times 3$, Polarised e^+/e^-
  ($\langle P \rangle = 40\%$)

HERA-1 (1993-2000) $\simeq 120$ pb^{-1}

HERA-2 (2003-2007) $\simeq 380$ pb^{-1}

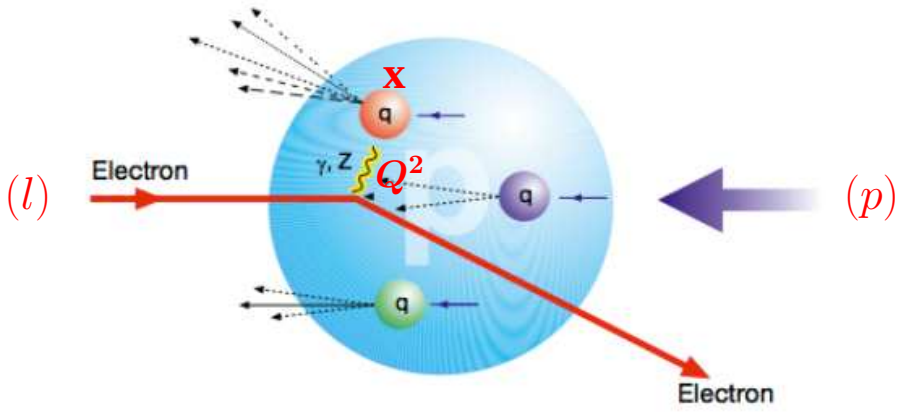
Final Data samples

H1+ZEUS: 2×0.5 fb^{-1}

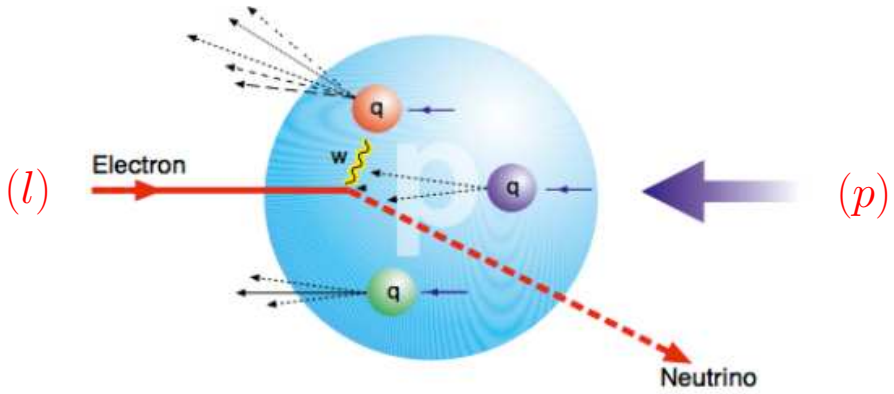


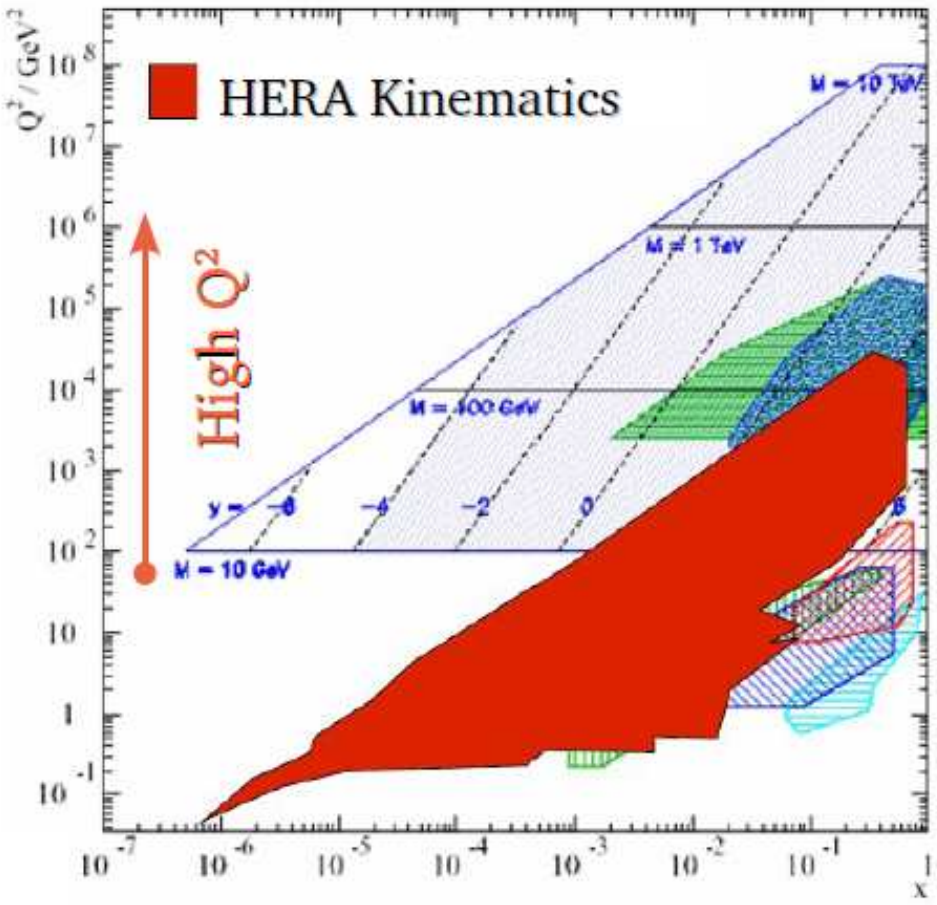
Deep-Inelastic Scattering at HERA

Neutral Current DIS: $ep \to e'X$



Charged Current DIS: $ep \to \nu X$





Kinematics:

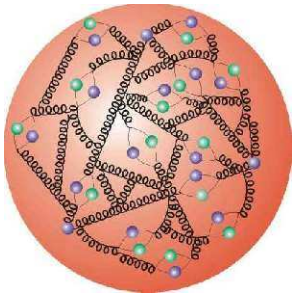
Momentum transfer: $Q^2 = -q^2$

Bjorken x: $x = Q^2/(2p \cdot q)$

Inelasticity: $y = (p \cdot q)/(p \cdot l)$

Physics landscape at HERA

- **HERA as Super-microscope**
  - ▷ Proton structure at high resolution
  - ▷ Impact for LHC



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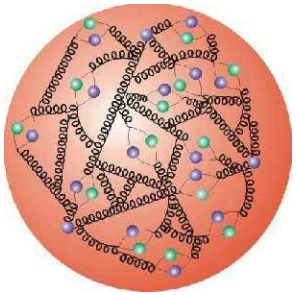
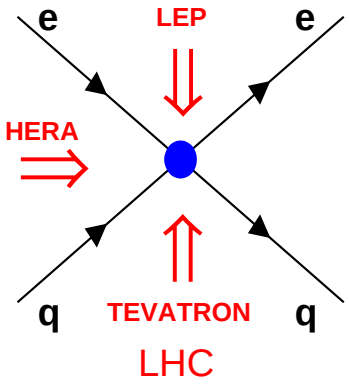


- **HERA as Energy frontier machine**
  - ▷ Electroweak unification at work
  - ▷ Anything beyond the Standard Model?



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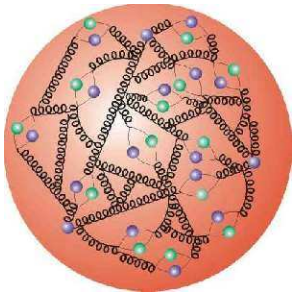

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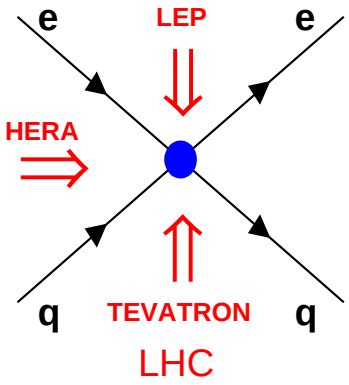
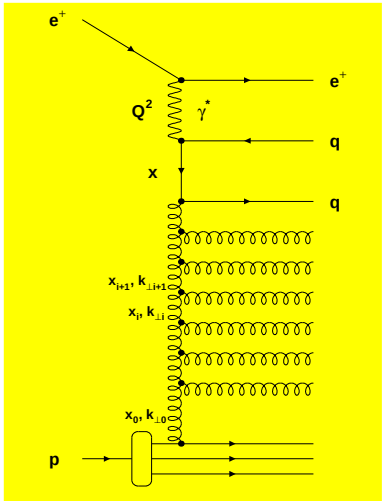


- **HERA as QCD laboratory**
  - ▷ Putting QCD in stringent tests with:
    - ○ Jets (parton evolution schemes, NLO QCD, α_s)
    - ○ Heavy flavor sector (multiscale problem: Q^2, M_Q, E_t)
    - ○ Diffraction (interplay of soft and hard physics)
  - ▷ HERA specifics: lox x physics



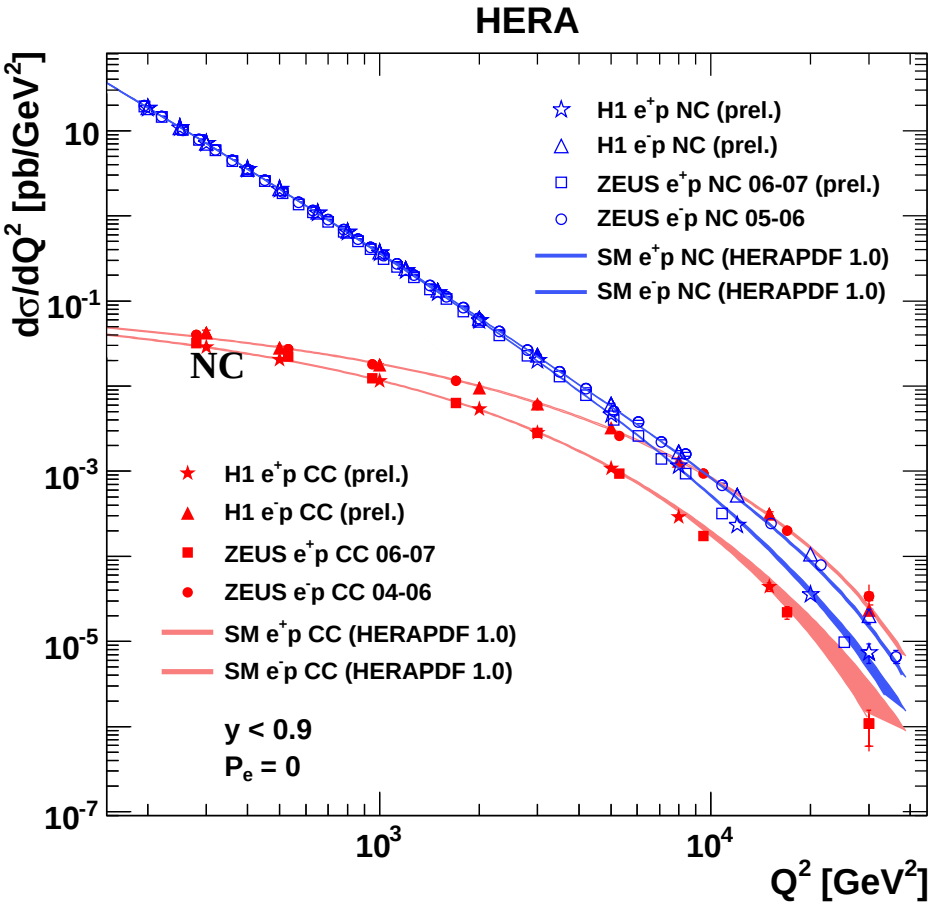
➠ **Search for Novel Phenomena**

➠ **Precision Measurements**

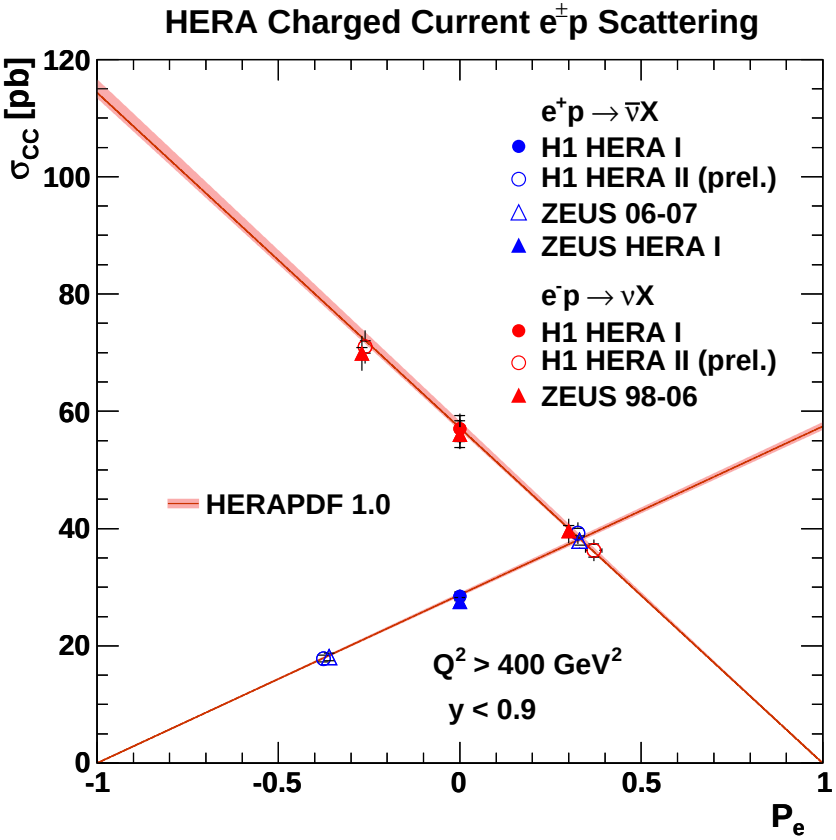
HERA at Energy Frontier

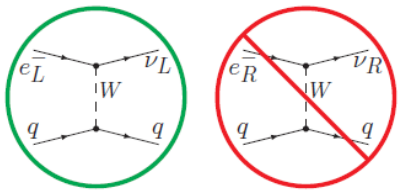
Unpolarized DIS cross sections

$$\sigma^{CC}_{\mathrm{pol}}(\mathrm{e}^{\pm}\mathrm{p}) = (1 \pm \mathrm{P_e}) \cdot \sigma^{\mathrm{CC}}_{\mathrm{unpol}}(\mathrm{e}^{\pm}\mathrm{p})$$



Electro-Weak Unification

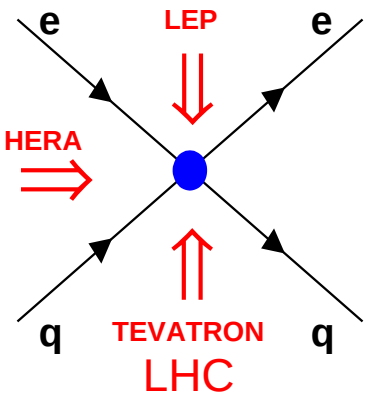




No W coupling to e^-_R and e^+_L

Anything beyond the SM ?

$\sqrt{s} = 319$ GeV

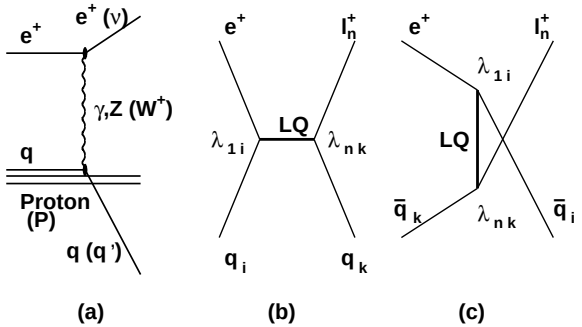


So far all NC and CC HERA data were in good agreement with the SM.
Try to look more carefully at the tails, using two strategies:

1. Specific BSM signals search (LQ, LFV, SUSY, ...) – guided by theory

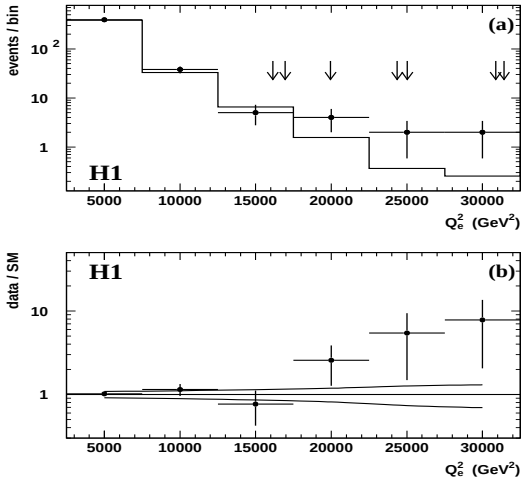
2. Model independent generic search (data vs SM) – guided by data

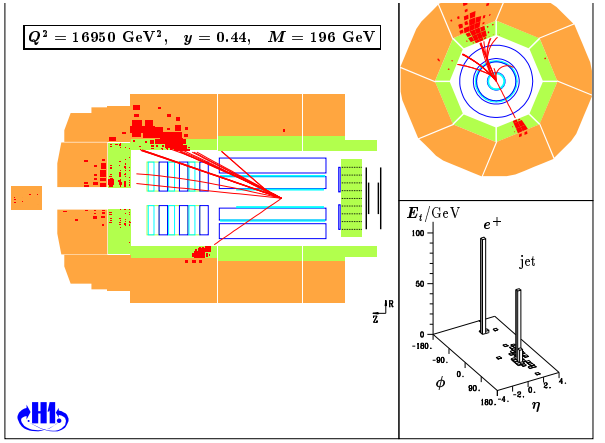
Leptoquarks ?



1994-97: High Q^2 events.

Rate in excess of Standard Model!





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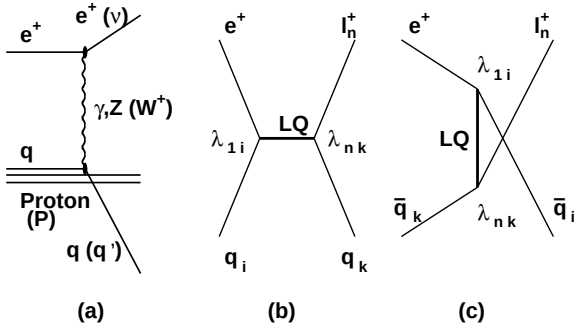

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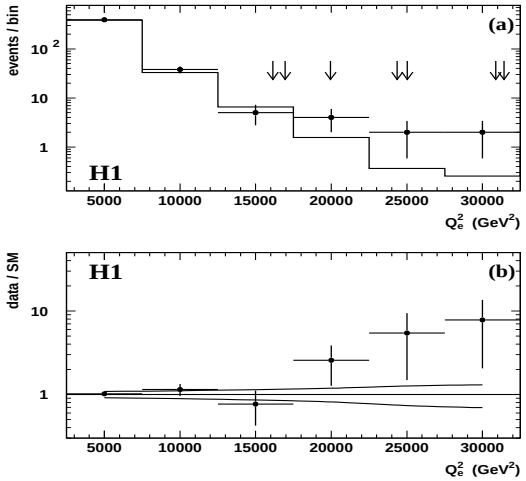
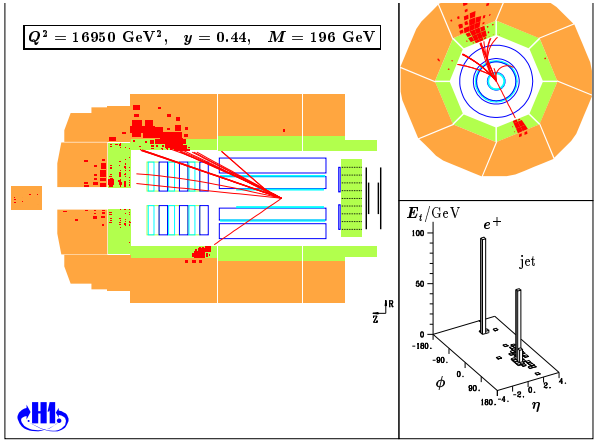
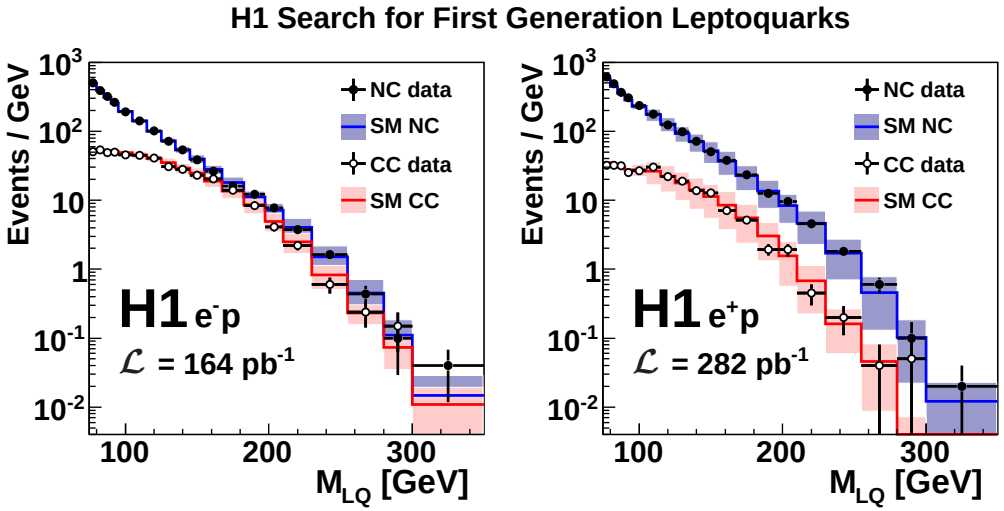
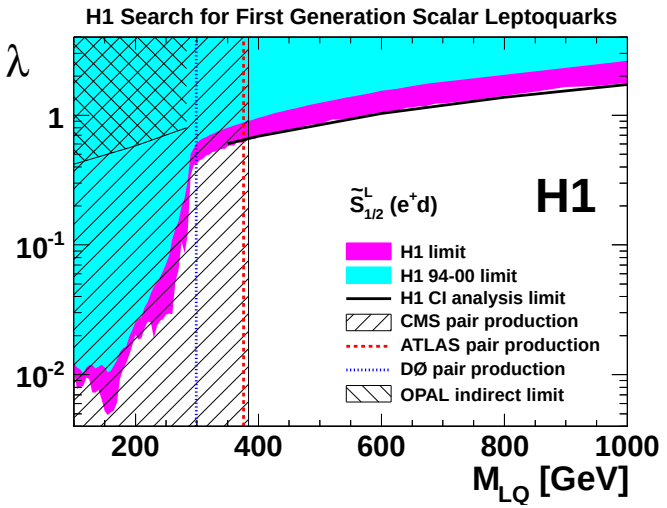




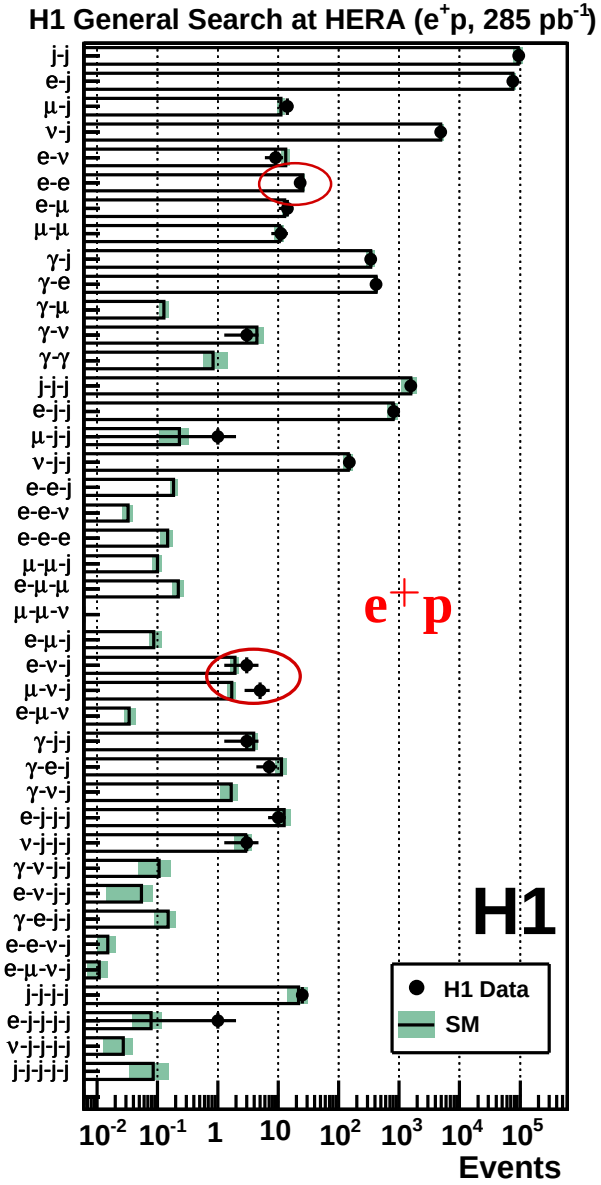
2011: Final status





Model independent search for New Phenomena

- Identify isolated objects:
  e, μ, γ, j, ν
- Select events, having at least two objects with high $P_T > 20\text{GeV}$
- Classify into exclusive channels containing from 2 to 5 objects
- Compare with SM predictions
  $\Rightarrow$ **good overall agreement**
- Find interesting regions with greatest deviations from SM in kin. distributions (M_{all}, ΣP_T)
  $\Rightarrow$ **Combine H1 and ZEUS data**



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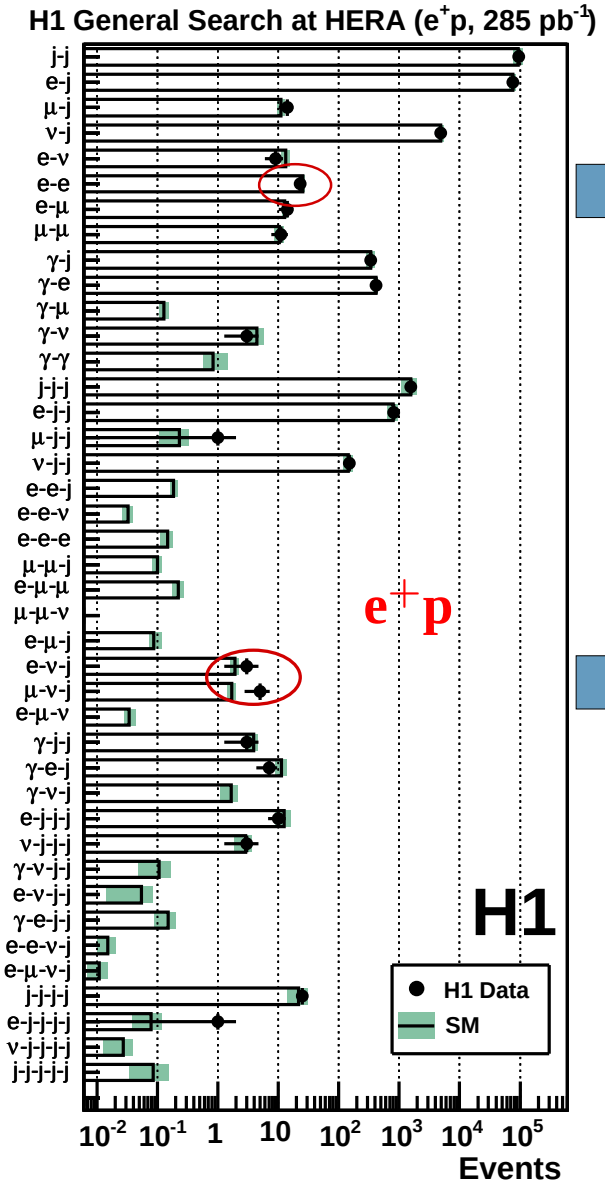
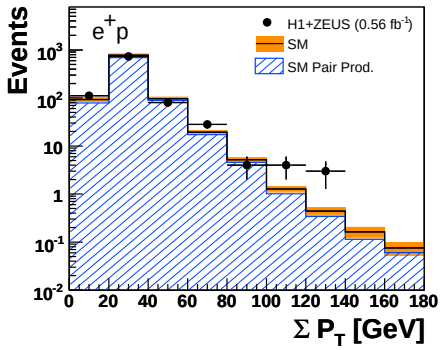
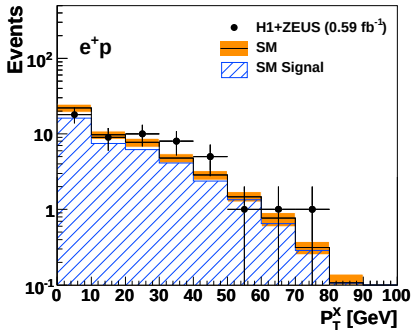


H1+ZEUS, 0.59 fb^{-1}



2.6σ

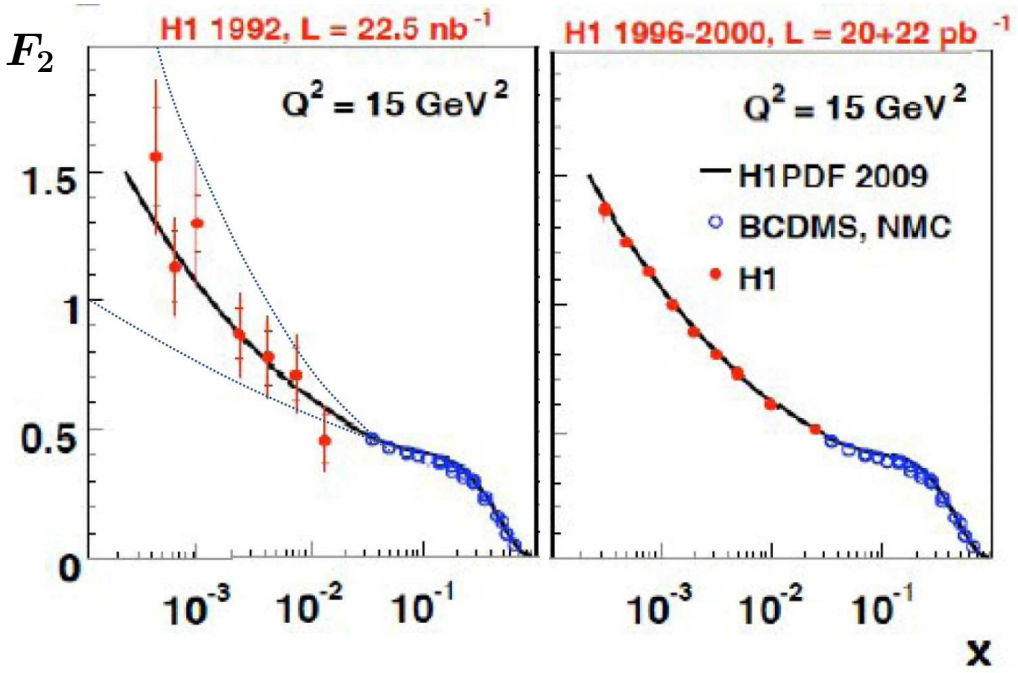


1.9σ

Largest observed deviations from the SM at HERA

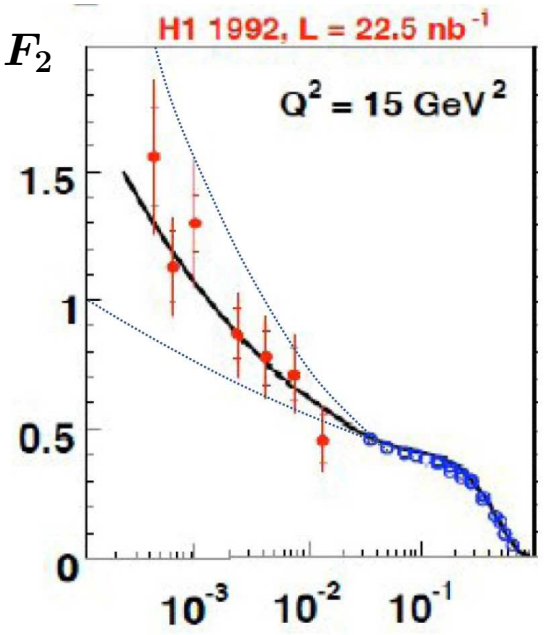
JHEP 0910:013 (2009)
JHEP 1003:035 (2010)

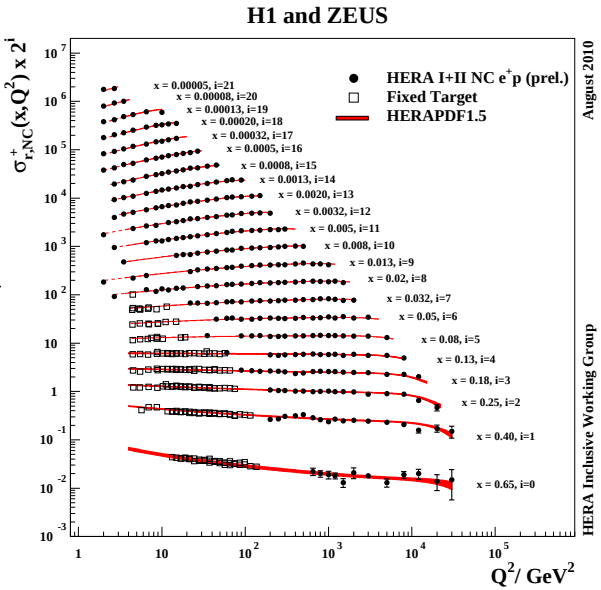
HERA as a Super-microscope

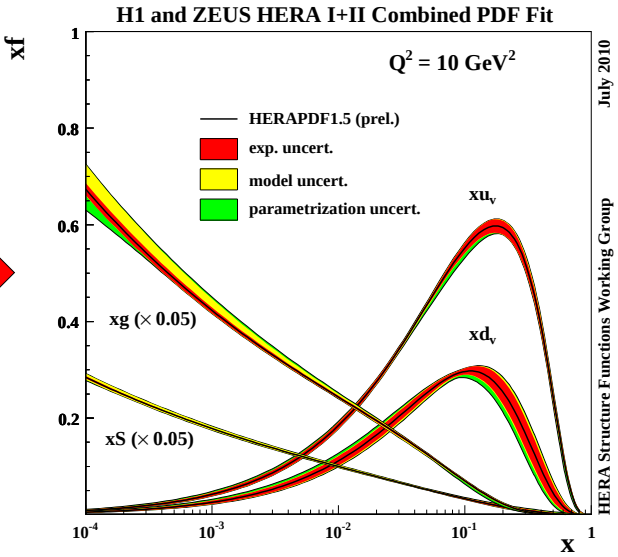


dotted lines show the spread in predictions
prior to HERA startup (1992)

HERA as a Super-microscope



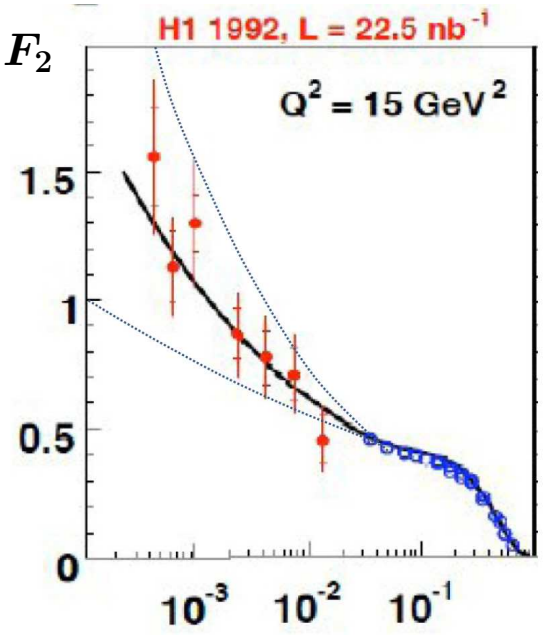


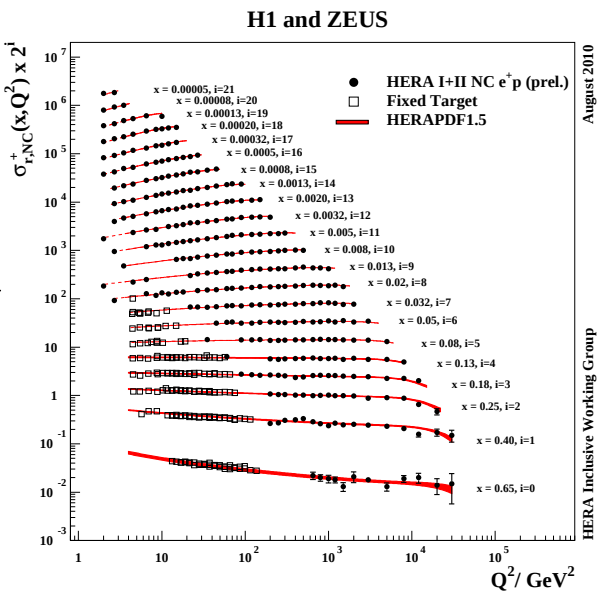


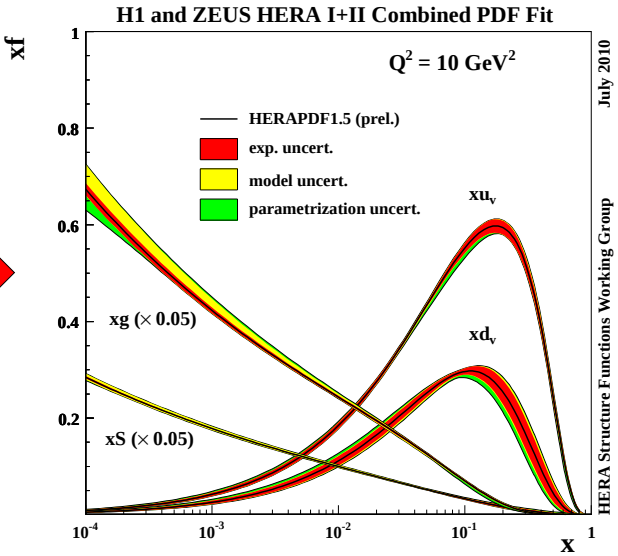
- Precision of $(1-2)\%$ in the bulk region
- Perfect desciption of the data by NLO QCD over many orders in x and Q^2
- Universal PDFs determined with error bands

⇛ Any substructures at 10^{-18}m ?

HERA as a Super-microscope







$$\frac{d\sigma}{dQ^2} = \frac{d\sigma_{SM}}{dQ^2} \cdot \left(1 - \frac{R^2}{6} \cdot Q^2\right)^2$$

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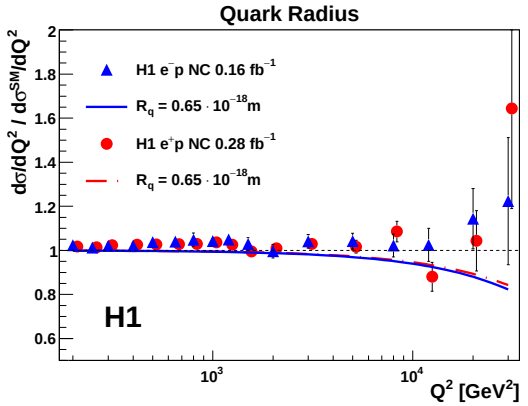


⇒ Any substructures at 10^{-18}m ?

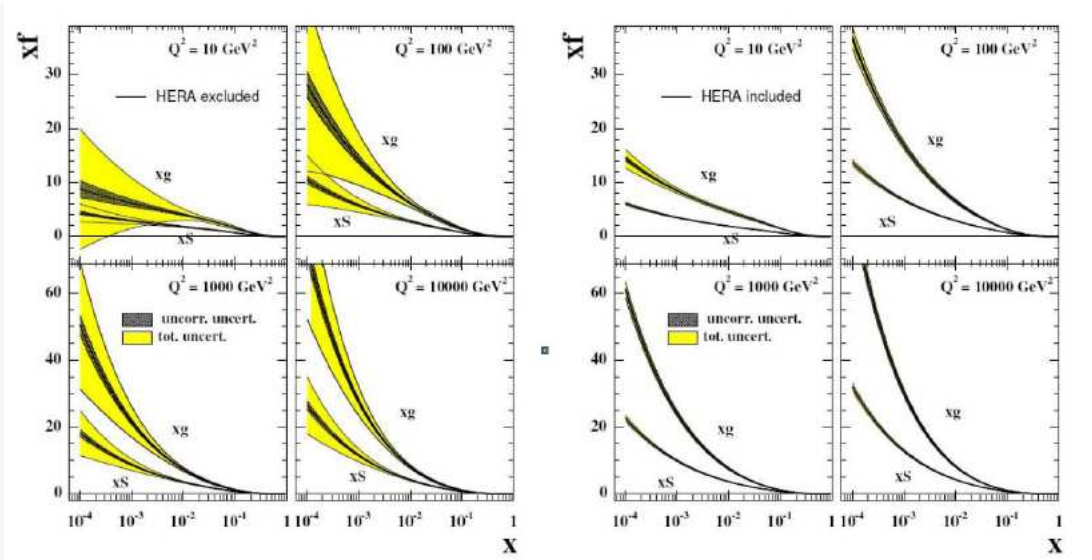
No. Quarks are still pointlike

Upper limit: $R_q < 0.65 \cdot 10^{-3}$ fm

HERAPDF for LHC

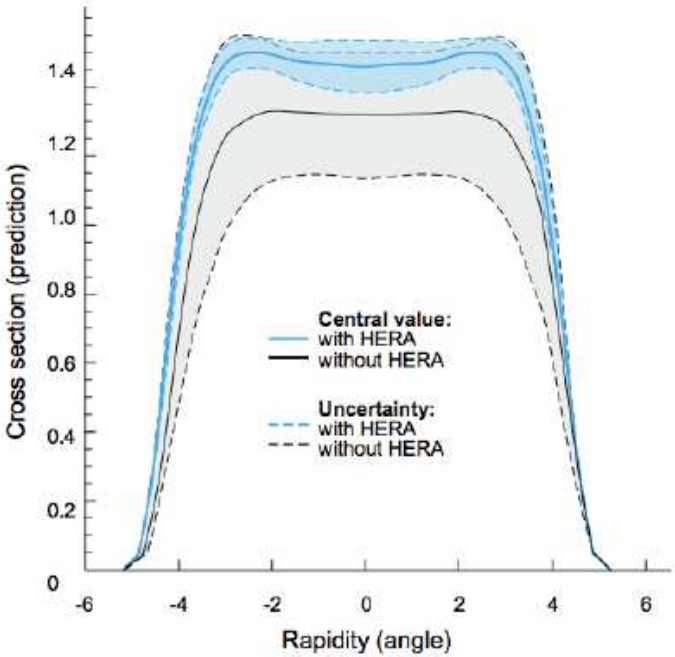
Knowledge of gluon without HERA data.

Knowledge of gluon with HERA

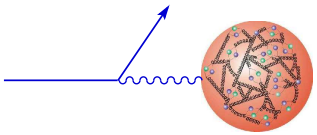


Cooper-Sarkar et al. : HERA-LHC workshop 2009

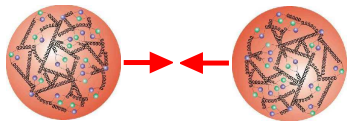
W^+ cross-section



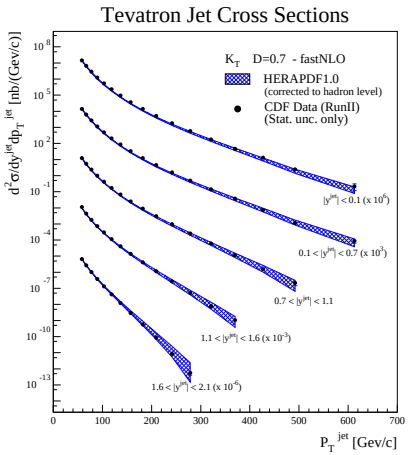
HERA

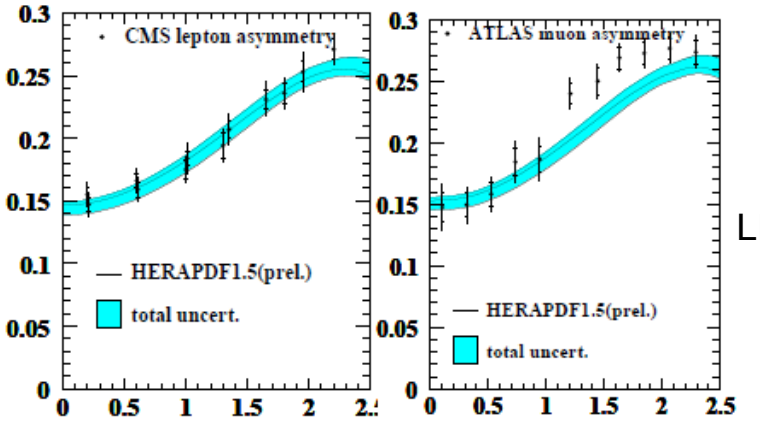


LHC



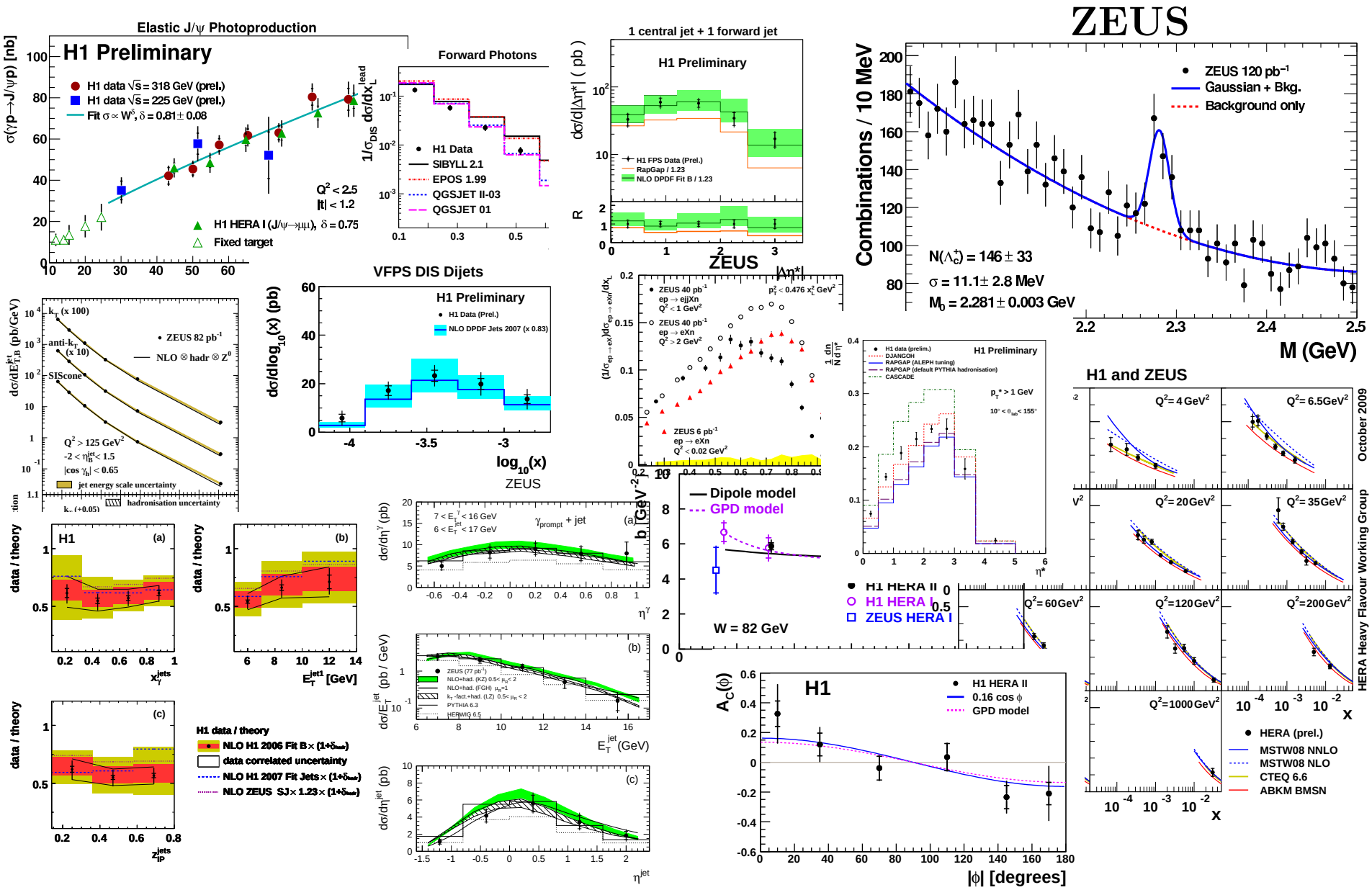
CDF Data (Run II)





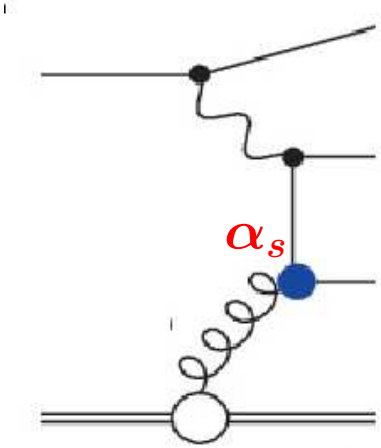
2011 LHC Data

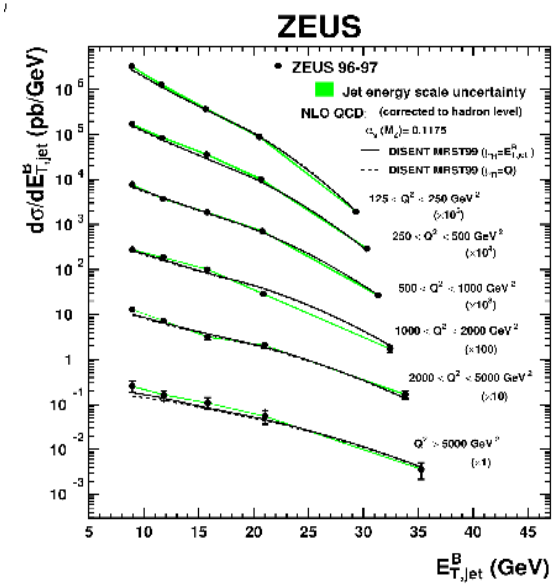
HERA as QCD factory

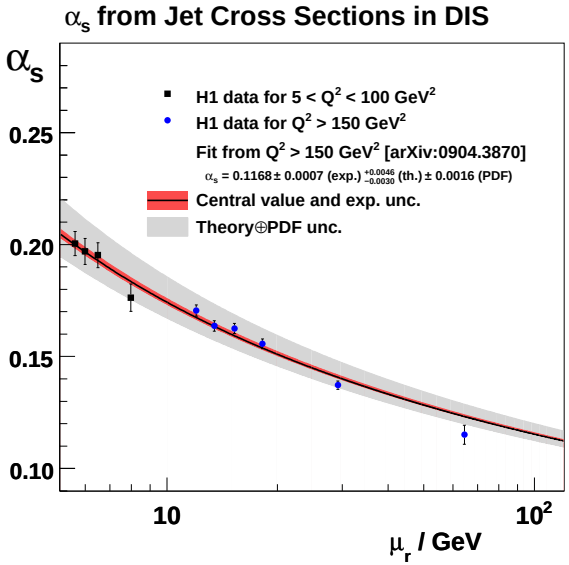


Jets at HERA

Precision QCD

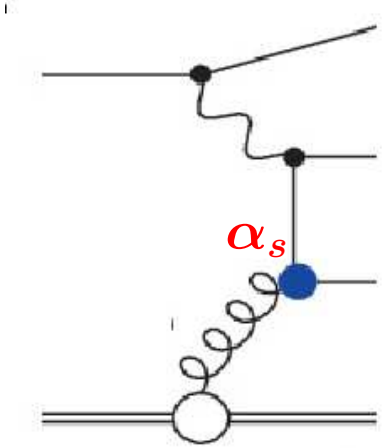


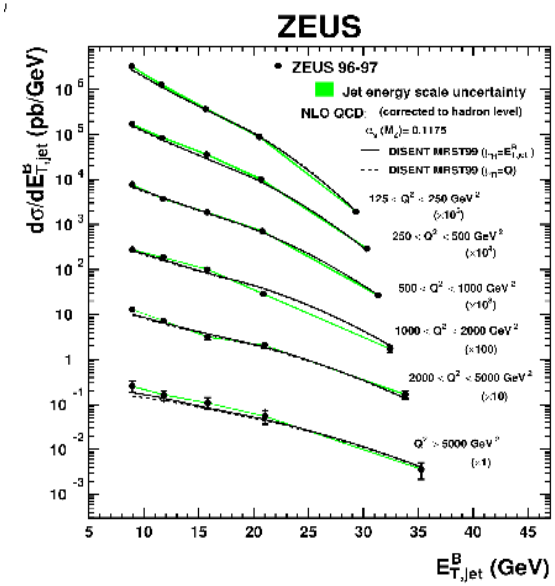


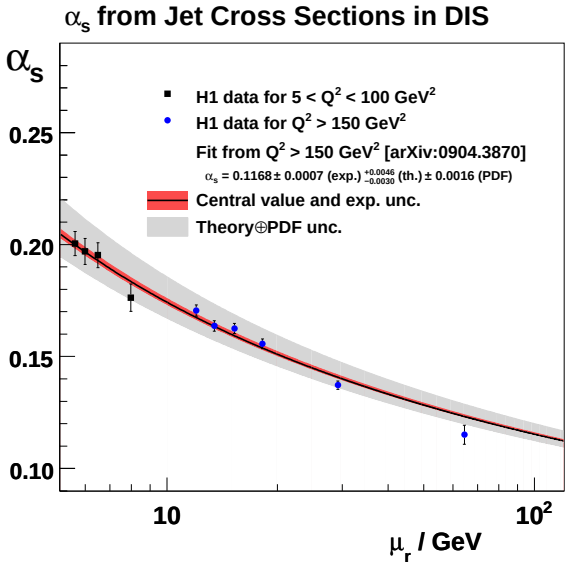


Jets at HERA

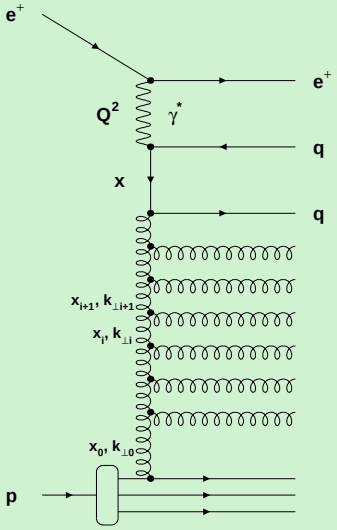
Precision QCD



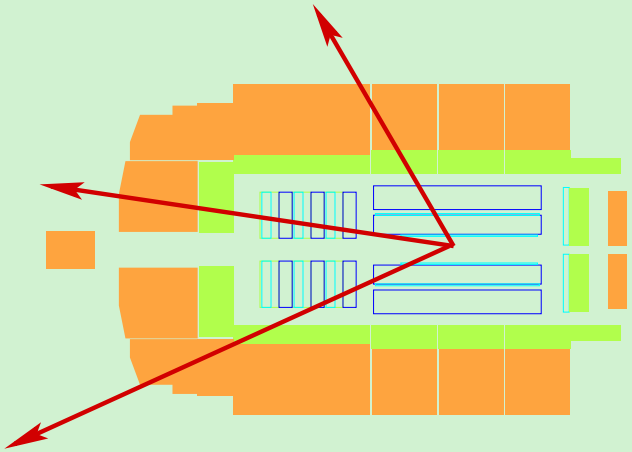




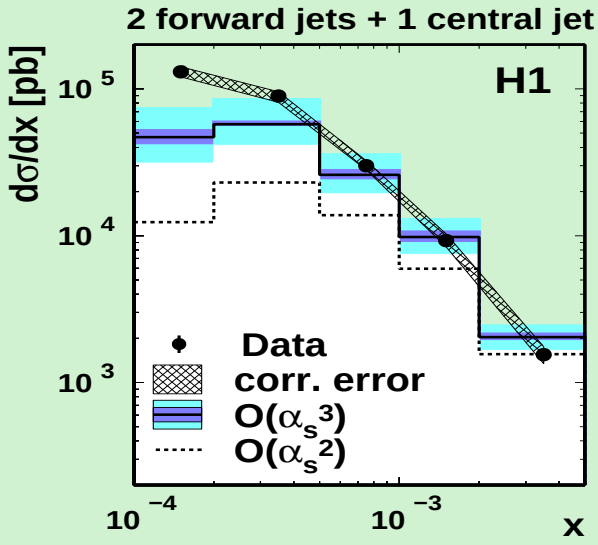
New dynamics?



look at different topologies
especially with forward jets

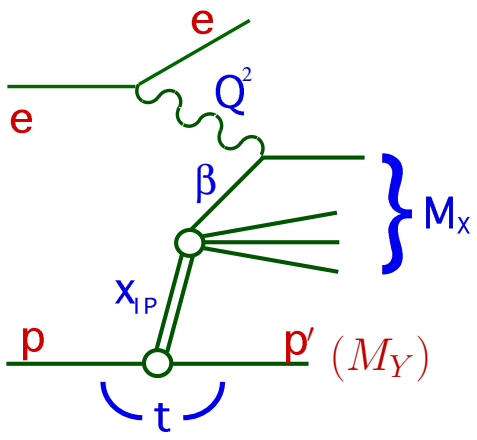


NLO DGLAP insufficient at low x



Diffraction at HERA

- Fundamental aim: understand high energy limit of QCD (gluodynamics; CGC ?)
- Novelty: for the first time probe partonic structure of diffractive exchange
- Practical motivations: study factorisation properties of diffraction; try to transport to hh scattering (e.g. predict diffractive Higgs production at LHC)



$$x_{I\!P} = \xi = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

(momentum fraction of colour singlet exchange)

$$\beta = \frac{Q^2}{Q^2 + M_X^2} = x_{q/I\!P} = \frac{x}{x_{I\!P}}$$

(fraction of exchange momentum, coupling to γ^*)

$$t = (p - p')^2$$

(4-momentum transfer squared)

Experimental methods:

1) selecting LRG events

2) detecting p in Roman Pots

FPS, VFPS

RFT: soft hh scattering vs QCD: deep inelastic ep scattering

• Hadronic degrees of freedom	• Partonic degrees of freedom
• Validity: large $s \gg t$	• Low x: $W^2 \gg Q^2, t$ $(Q^2/W^2 \simeq x \ll 1)$
• $I\!P$ dominates: $\alpha_{I\!P}(0) > \alpha_{I\!R}(0)$ $\rightarrow \sigma_{\rm tot} \propto s^{\alpha_{I\!P}(0)-1}$	• gluons dominate: $xg(x) \gg xq_{val}(x)$ $F_2(x,Q^2) \propto xg(x) \sim x^{-\lambda}$
• Unitarity corrections unavoidable $(\sigma_{\rm tot} \leq \ln^2(s/s_0)$ at $s \rightarrow \infty)$	• Saturation of the $xg(x)$ (non-linear effects, shadowing, ...)
• When? $s_{sat} = ?$	• $x_{sat}(Q_{sat}) = ?$
• First to be seen in diffraction: $\sigma_D \propto s^{2(\alpha-1)}$	• First to be seen in diffraction: $\sigma_D \propto \lvert xg(x)\rvert^2$

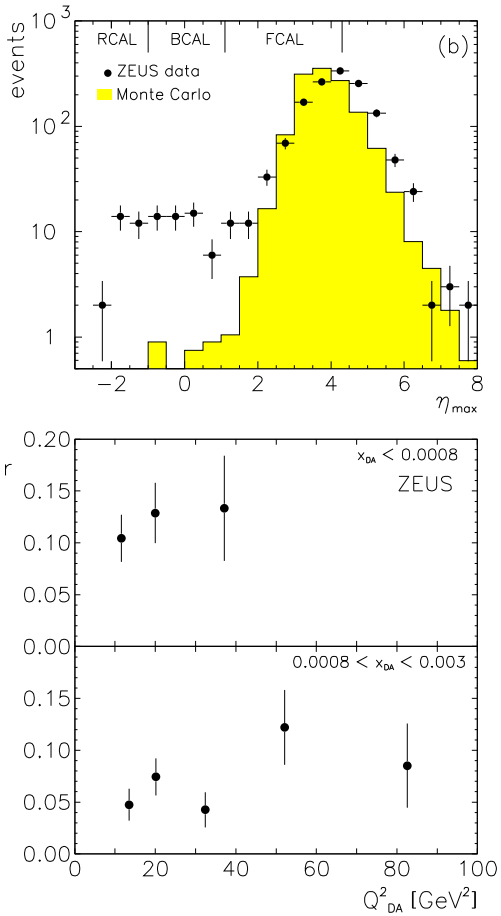
$\Rightarrow$ Diffraction $\equiv$ Physics of the Pomeron, the essence of strong interactions

$\Rightarrow$ Diffraction $\equiv$ Gluodynamics, the essence of QCD

(in high energy limit)

Inclusive Diffraction in DIS

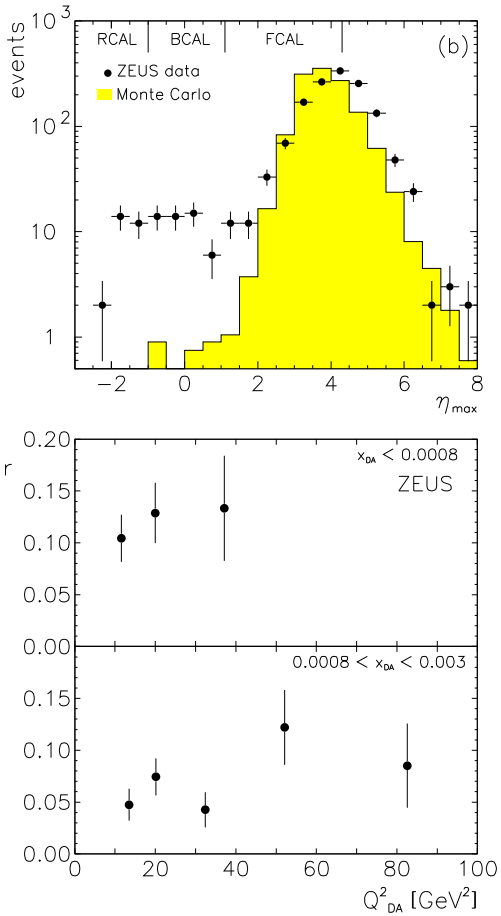
ZEUS-1993



First observation
of diffraction in DIS
1992 data, $\mathbf{24.7}$ nb^{-1}

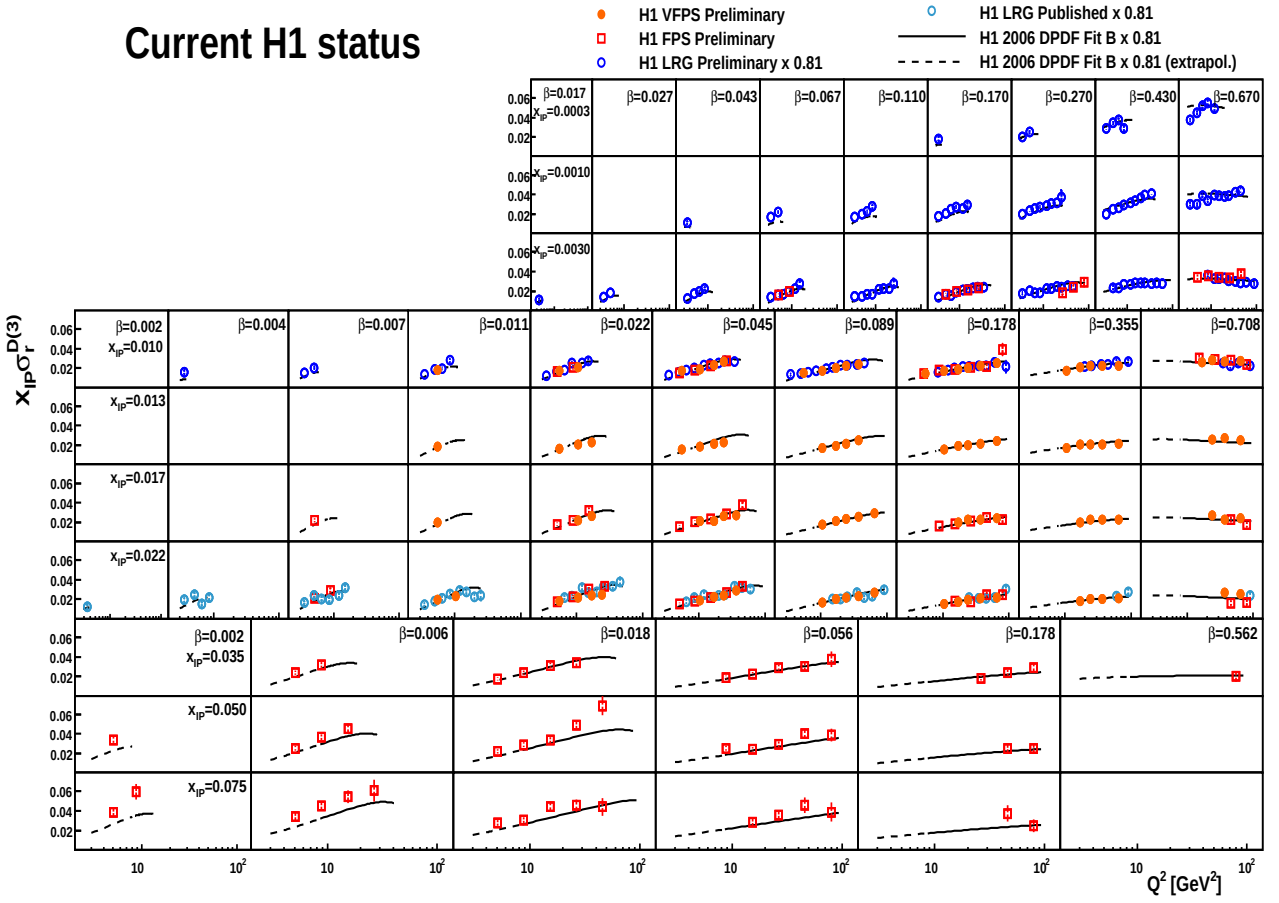
Inclusive Diffraction in DIS

ZEUS-1993



First observation of diffraction in DIS 1992 data, 24.7 nb^{-1}

Current H1 status



LRG

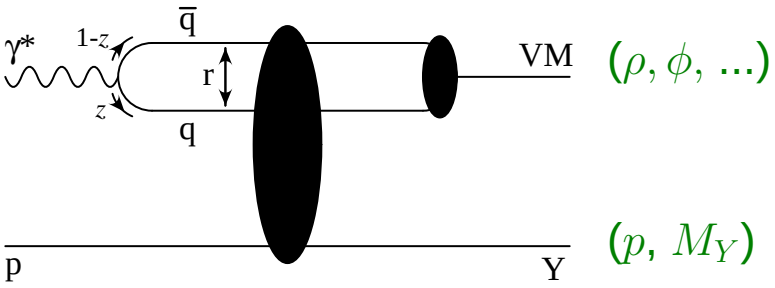
VFPS

FPS

- Compelling confirmation of the NLO QCD picture of diffraction over a wide kinematic range. Clear candidate for the textbook!

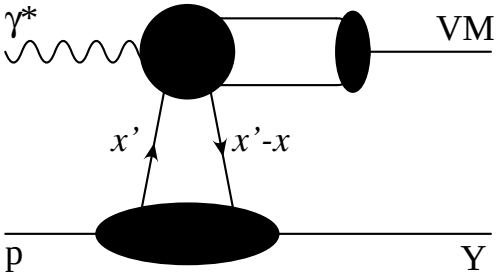
Exclusive Diffraction at HERA

Since its advent HERA radically changed landscape in this field:



$(\rho, \phi, ...)$

(p, M_Y)



$(\rho, \phi, ...)$

(p, M_Y)

Development of colour dipole approach from VM production to DIS (Nikolaev, Zakharov, Bjorken,...)

Collinear factorisation framework $\Rightarrow$ access to GPDs and parton correlations in the proton

Relation to F_2 and σ_{tot} via Optical Theorem

Universal Pomeron vs perturbative gluons, interplay of soft and hard physics

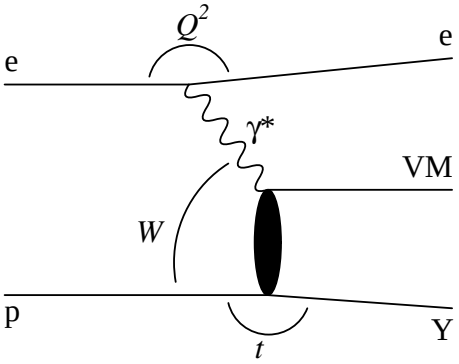
Multi-scale problem: Q^2, t, Mass - what is the relevant scale here?

Check Regge factorisation hypothesis at the proton vertex

Since γ and VM are spin=1 particles $\Rightarrow$ sensitivity to helicity properties of diffractive scattering

$\Rightarrow$ **Rich physics program**

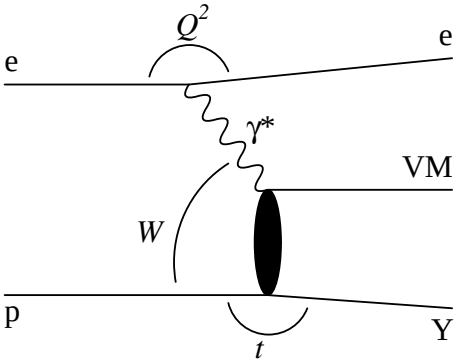
Diffractive electroproduction of ρ and ϕ mesons at HERA



Editors: X. Janssen, P. Marage

Volume: 111 pages, 48 figures, 53 tables

Diffractive electroproduction of ρ and ϕ mesons at HERA



Editors: X. Janssen, P. Marage

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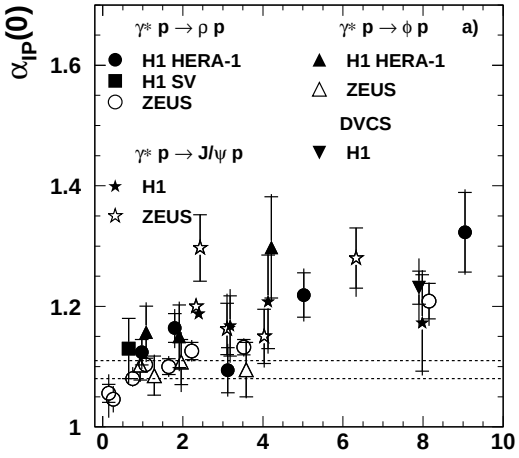
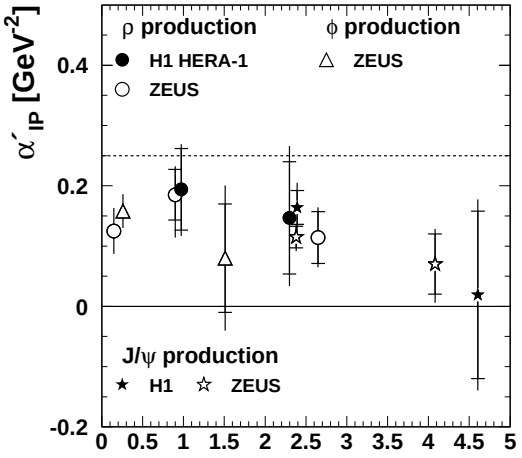
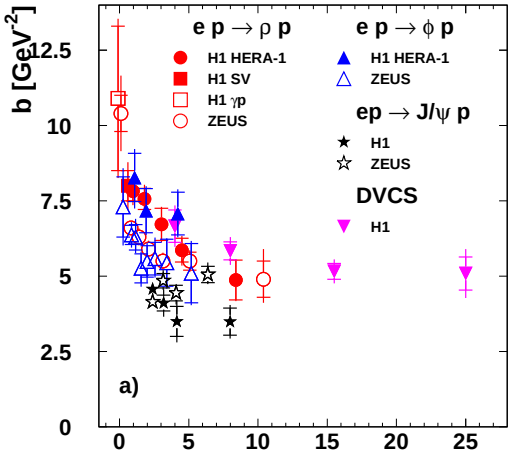
$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} \cdot t$

$\sim$ transverse size







Transition from soft to hard behavior at $\mu^2 \simeq 4 - 5$ GeV^2

Further Diffractive Topics

- Jets in diffraction
- Investigation of QCD factorization breaking (γp vs DIS)
- Extracting DPDFs using global QCD fit of all available HERA data

Ongoing Diffractive Analyses

- Jets in diffraction
- Investigation of QCD factorization breaking (γp vs DIS)
- Extracting DPDFs using global QCD fit of all available HERA data

In all these analyses activity and great expertise of Belgium groups is absolutely valuable.
Using now HERA results and experience for low x physics and diffraction at LHC





Summary

- Standard Model survived 1 fb^{-1} of **HERA** data and is still in a good shape. Next challenge is now coming from the **LHC** - stay tuned!

- Combining H1 and ZEUS data allowed proton structure to be measured with unprecedental precision

- NLO DGLAP is surprisingly successful down to low Q^2 and low x in describing bulk of HERA data. However, some room for parton evolution beyond DGLAP is found at specific phase space corners $\Rightarrow$ important message for LHC

- Gained new insights into high energy diffraction: Pomeron under the HERA microscope shows complicated interplay of soft and hard phenomena. Understanding colour singlet exchange remains a major challenge in QCD

- There is a wealth of unique data from HERA. All efforts are taken to save them for possible future analysis, MC models tuning and outreach purposes

More heritage from HERA

★ Unique experience how to build and run such a complicated asymmetric collider (SC magnet technology, beam diagnostics, specific background problems etc.) Invaluable for any future ep machine (eRHIC, LHeC, ...)

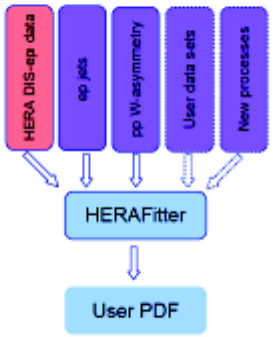
★ HERAFitter – A platform originally developed at HERA and now evolved into an open source project including also LHC experiments and theory groups

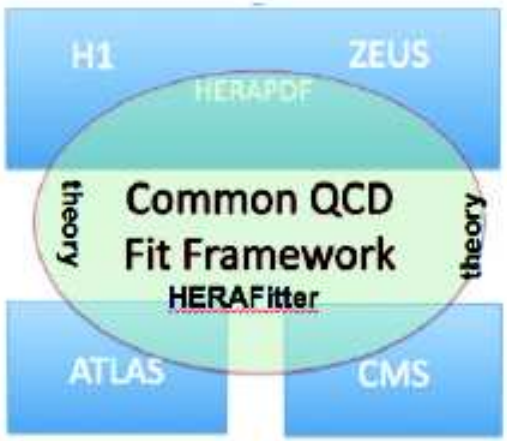
★ Data Preservation Project – Another DESY initiative started in 2008 which by now includes all major HEP experiments and recognized at high international level

HERAFitter

HERAFitter: Proton Structure from HERA to LHC

- **Open access QCD/PDF infrastructure based on collaborative approach of HERAPDF**
- **Exploit DESY expertise in the field of Proton Structure**
- **Promote the HERA Physics at LHC:**
  - **Endorsed by H1, ZEUS, ATLAS, CMS**
- **Project discussed with and supported by the PRC**
- **First LHC publications based on HERAFitter**



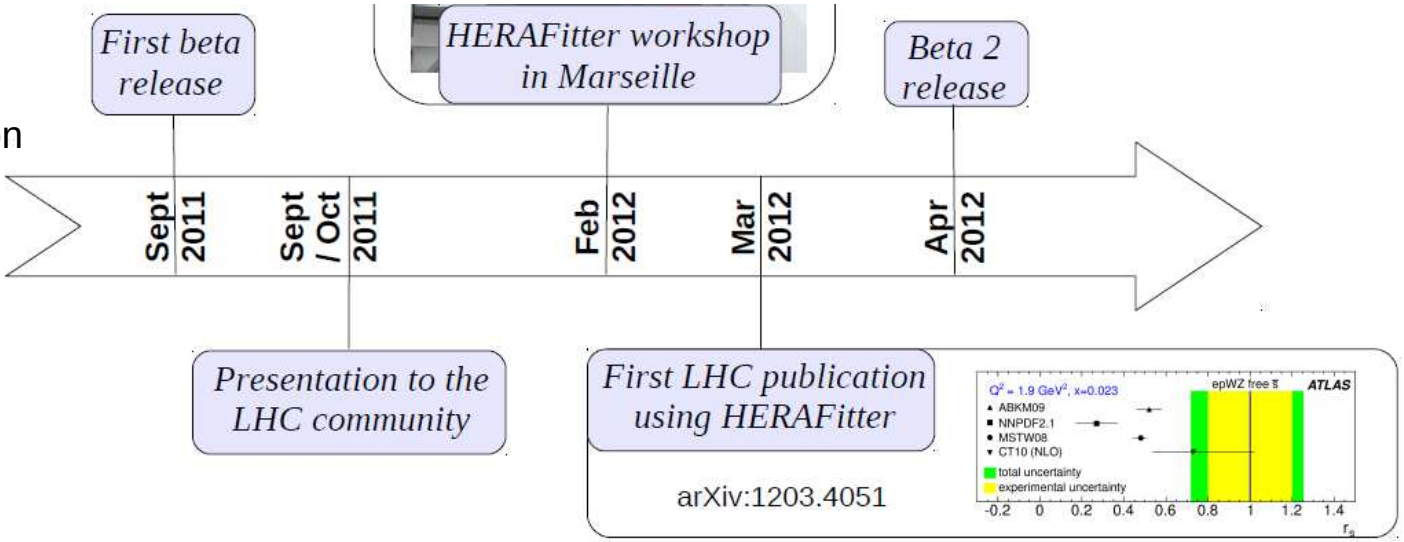


Data:

- HERA, Tevatron, LHC fixed target experiments
- Inclusive DIS, Jets, Diffraction Drell-Yan, Top, W, Z prod.

Theory:

Different HF schemes,
Different evolution codes,
FastNLO, Applgrid, Hathor,
NNPDF reweighting,
Dipol model

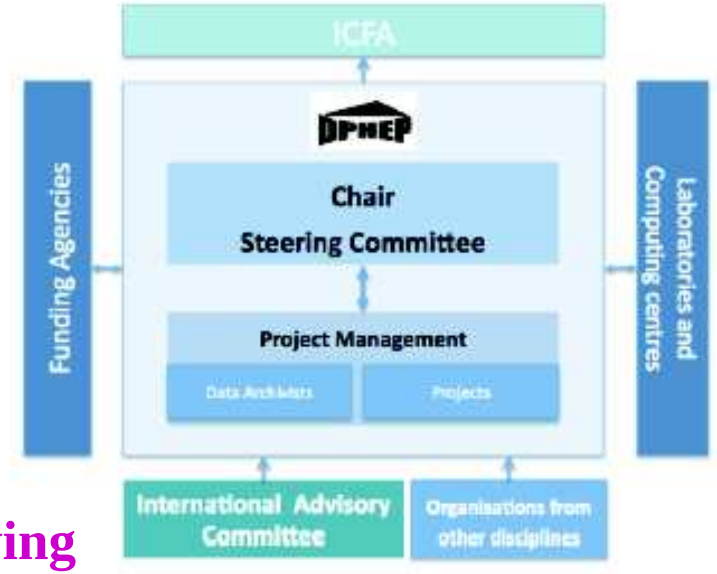


http://projects.hepforge.org/herafitter

DPHEP Project

- All major HEP experiments and organisations involved
- Several models adopted for presevation strategy, including data integrity checks and automated s/w validation.
- Non-digital Documentation, Education and Outreach

- 5 Workshops held in 2009-2012
- Important milestone reached with recent publication
- DPHEP is now moving to a new phase
- Funding is needed, from within HEP, or from EU (FP8)
- Next Workshop is in Marseille, 19-21 November 2012



The project is endorsed by ICFA and is in full swing

1992 - Startup; 2007 - End of Data taking; 2012 - Finilizing Analyses

These were two extremely exciting decades!

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Sad ?

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These were two extremely exciting decades!

Sad ?

No! Deeply thinking...